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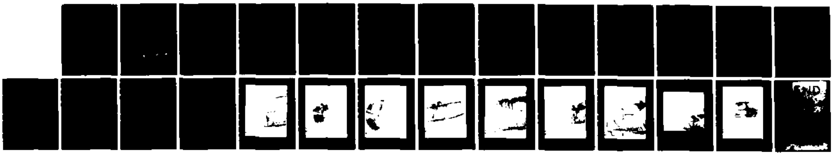

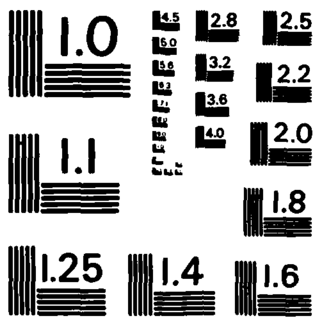

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Offshore Oil Platform Underwater Inspection: A Study and Evaluation of a Scanning Beam Sonar

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This report examines a method to perform unannounced inspections of producing offshore oil platforms for possible structural deficiencies. An off-the-shelf scanning beam sonar imaging system was selected and evaluated at a candidate platform. The test results indicated that the scanning beam equipment must be located close to the structure for usable images. This requirement would necessitate permission from the operator. Possible modifications to the equipment tested are recommended.

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CONTENTS

OFFSHORE OIL PLATFORM UNDERWATER INSPECTION:
A STUDY AND EVALUATION OF A SCANNING BEAM SONAR

INTRODUCTION

This report describes the results of a study to determine the feasibility of using a scanning sonar for monitoring the structural integrity of offshore oil platforms. The study was performed by the Naval Research Laboratory (NRL) in response to a request from the Technology Assessment and Research Program, Minerals Management Service.

The methodology used in this study was to determine the theory, operation, and capability of various underwater inspection systems. A candidate inspection system, which uses a mechanically scanned sonar beam, was selected for evaluation. The evaluation system is a UDI AS 360 Integrated Scanning Sonar, which is manufactured by UDI Group Ltd., Aberdeen, UK. SUBMAR, Inc., of Houston, Texas, supplied the UDI 360, and a work boat (a jack-up barge) for the trial platform inspection on a lease basis.

The system concept, equipment description, evaluation results, conclusions, and recommendations for future action are described in the remainder of this report.

SYSTEM CONCEPT

Problem Definition

The Minerals Management Service desires a means of inspecting the submerged sections of producing offshore oil platforms for possible structural deficiencies. It is desirable to perform these inspections on a random basis without obtaining permission from the platform operator to moor to or board the platform. The inspection equipment should be portable and capable of operating from an unspecified vessel of opportunity.

Assumptions

In this study we invoke the following assumptions:

- o Inspection Vessel - The inspection vessel is, in the least, a work boat of 15 m in length with a powered lift mechanism for over-the-side deployment of a 100 kg inspection package.
- o Distance - A safe operating distance from the platform is 50 m.
- o Depth - The maximum inspection depth is 300 m.
- o Resolution - A resolution of 15 cm is desired for inspection of structural members.

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- Water Visibility - The visibility is expected to be only a few meters due to turbid water.

- Equipment - The candidate inspection equipment to be evaluated should be available in off-the-shelf or prototype form.

Summary of Possible Methods

Among the possible methods of underwater inspection are:

1. Direct viewing by divers

2. Underwater photography

3. Underwater television

4. Scanning beam sonar imaging

The first three methods require a close-in inspection of the structure. For example, the diver or lens system would have to approach the structural member under inspection to 3 or 4 m. This action would require coordination with platform operator for safety reasons. Boarding of the platform may also be required. Only the latter scanning beam sonar imaging method is considered feasible for a stand-off inspection.

Scanning Beam Sonar

In a scanning beam sonar, the transducer beam is mechanically or electronically scanned about some axis, as shown in Fig. 1. A mechanically-scanned sonar uses a transducer mounted on a rotating scanning head. The transducer produces a narrow, fan-shaped beam (Fig. 1). Normally the angle of rotation is 360 deg when the axis of rotation is vertical. This provides for a plan view of the inspection area.

The maximum range of the mechanical scan sonar is dependent on the scan rate, beam width, and frequency. The scan rate must be sufficiently slow so that the return signal from an object within the desired range and field of view can be received by the rotating narrow beam transducer. The maximum angle of rotation between transmission and reception is about one beam width, depending on the sharpness of the beam. If the beam width is increased, so as to increase range, the resolution of the system is reduced. A fixed beam width of 1 to 3 deg is normally used, while scan rate is selected on the basis of the desired range.

The resolution of the scanning sonar is proportional to frequency. However, the frequency is limited to less than one megahertz, due to severe attenuation of acoustic energy in water at the higher frequencies.

In an electrically scanned sonar a wide beam is used to insonify the viewing area, and an array of receivers is used to receive the reflected signals. This is similar to a phased array radar system. Here the resolution is dependent on the number and spacing of the receiving elements, and the frequency. The scan rate is subject to the same limitations as the mechanically-scanned system. The cost and electronic complexity of an

electronically-scanned system is much greater than the mechanically-scanned configuration.

Scanning Beam Image

In a scanning beam system the sonar return data is normally displayed on a cathode ray tube (CRT) in a plan position indicator (PPI) format. Each return is displayed as a dot on the CRT with the radial distance from the center respresenting range. In past systems, a long persistance CRT was used to retain the resultant image during the scan angle, i.e., 360 deg. This resulted in a difficult to interpret and fading image. In the evaluation system, the scan signals are converted to digital data and stored in a computer memory. The CRT is updated line by line under control of a microprocessor. This provides a good image which does not flicker or fade. The gray levels of the pixels displayed are determined by the intensity of the sonar return.

EQUIPMENT DESCRIPTION

The UDI AS 360 Scanning Sonar System (AS 360) is an off-the-shelf, commercial system which is used in a large variety of underwater tasks. For example, the AS 360 has been used for platform inspection, pipeline surveys and trench profiling, debris location and site inspection, etc. The AS 360 is representative of modern scanning beam sonar systems. We provide a brief technical description of the AS 360, and its operating modes and limitations.

AS 360

The AS 360 consists of a sonar head, and a display and control unit. An umbilical with 5 conductors is used to connect the two units.

A. Sonar Head

Dimensions and specifications of the sonar head are given in Table 1. As shown, the transmit beam width is 1.8 deg horizontal and 27 deg vertical. The unit transmits 500 kHz acoustic pulses of 100 microsecond duration. The receiver beamwidth is 3.4 deg horizontal and 27 deg vertical. This allows for reception of returns while the transducer head is rotating. Scan rate is dependent on the range selected, which varies from 10 to 100 m.

B. Display and Control Unit

The primary function of the display and control unit (DCU) is to process and display the scanning beam sonar data. This unit also provides power to the sonar head and enables control of the range and scan angle.

The acoustic data from the sonar head is processed by the DCU electronics and stored in binary form in a 256 x 256 x 3 memory matrix. This data is displayed on a standard nine inch video monitor, which is an integral part of the DCU. The data is displayed in 256 x 256 pixels with eight gray levels. A microprocessor is used to control the data flow from memory to the video monitor, and to preprocess the data. A line by line refresh mode is used.

The data is displayed in PPI format, as previously described. This provides for a television-like image of the object on area scanned. An auxiliary video output is provided for recording purposes. The position of the scan line origin is variable, for example, from the center of the video monitor to the lower center or corner. This feature enables the operator to view a segment of the area being scanned over the full screen.

The pertinent characteristics of the DCU are given in Table 2.

Scan Method

When the AS 360 sonar head is deployed so that the beam is rotated about the vertical axis (Fig. 2a), a plan view of the inspection area is shown on the video monitor. If the beam axis of rotation is horizontal (Fig. 2b) a profile view of the scan area is provided. In both viewing modes, the range scale is 10, 20, 40, or 100 m, and the scan angle is 15, 30, 60, 90, 180, 270 deg, or continuous.

Deployment

The sonar head was deployed by cable from a lift arm over the side of a work-boat (Fig. 3). A 40 kg weight was suspended from a bridle under the sonar head in order to keep the cable vertical in the water. A line was also attached to the suspension harness and attached to the survey vessel for additional stabilization. It is important to minimize any horizontal or vertical motion of the sonar head. Excessive motion could result in a blurred image, i.e., motion blur.

Limitations

The AS 360, or any other scanning beam system when deployed as described, is probably limited to use in sea states of 1 or less. It is expected that use in rough seas would result in increased noise due to additional surface reflections, and in-motion blur. The activity on or around the platform should be minimal. For example, water bubbles due to supply boats or water discharges would cause additional noise in the sonar data.

FIELD EVALUATION

The AS 360 was deployed as described and the results were recorded on U-Matic type video cassettes (3/4 inch). The original U-Matic tape data was copied onto a VHS format tape cassette at NRL. This conversion was performed in order to provide for better quality images with the video cassette recorder (VCR) in the "pause" mode. The intent here was to photograph various images with the VCR in "pause". When the images were viewed from the VHS tape, with the VCR in "pause", the image quality was better than from the U-Matic VCR in the same mode. However, the picture quality was still not as good as with the VCR in the "play" mode.

The images shown here are photographs of the video monitor with the VCR in the "play" mode (VHS copy). At this point we stress that the images shown are degraded versions of the originals due to photography and printing.

In some cases the photographs were rotated by 90 deg from the position shown on the video monitor. This rotation was done so that the reader can view the image from the correct perspective.

Platform Structure

A plan view of the platform structure inspected is sketched in Fig. 4a. This view shows the relationship of the service platform, drilling rig, supply boat, and jack-up barge. Piping used for corner members of the service platform are about 1 m in diameter. Cross members shown in sonar pictures are about 35 cm in diameter. Risers inside the platform are 30 to 60 cm in diameter.

View 1

In Fig. 5 a sonar image profile view of the production platform is shown. The sonar head is deployed on the outside corner of the platform, as illustrated in Fig. 4(a), position 1. The approximate distance of the sonar head from the platform is 10 m. The scan angle is 180 deg, and the range is set at 40 m. Note that the origin of the scan line (sonar head) is located in the center of the far right hand edge of Fig. 5, and the distance from the right to left edges is 20 m.

The white horizontal lines in the center and bottom of Fig. 5 are surface and bottom returns. The corner leg of the platform is shown in the lower center of the image.

View 2

Figures 6 and 7 shows a plan view of the platform, with the AS 360 range setting at 40 and 20 m, respectively. The sonar head is located as shown in Fig. 4(a), position 2 and is scanning continuously. The approximate distance of the sonar head from the platform is 5 m. Two platform corners, connected by cross structure, are visible in the upper right quarters of both Fig. 6 and Fig. 7. The block of white circles inside the structure, which are visible in Fig. 6 and Fig. 7 are vertical pipes (risers). These risers are about 30 and 60 cm in diameter. The three straight lines in the center of the scan are legs of the jack-up barge.

View 3

Figures 8, 9, and 10 show a profile view of the platform with the sonar head located as illustrated in Fig. 4(b). The approximate distance of the platform from the sonar head is 5 m. Let us first examine Fig. 8. The upper and lower heavy, white, near horizontal lines in Fig. 8 are the surface and bottom returns. The series of vertical lines to the left center and between the surface and bottom returns are the vertical risers in the platform. As previously stated, the risers are 30 to 60 cm in diameter. The vertical line to the right of the risers is the corner of the platform, and the diagonal lines emanating from the corner leg are also structural members. Note the short parallel lines on either side of the corner leg (near center of Fig. 8). These are anodes. The range setting in Fig. 8 is 20 m, and the scan angle is 360 deg. The origin of the scan line is in the center of the display. Note the increase in surface boundary noise is caused by a supply

boat which moored to the platform with its prop wash directed through it. Compare this with Fig. 5. Note also that the vertical members appear to bend. This effect is due to sensor motion.

In Fig. 9, only the presentation on the display is changed. Here the origin of the scan line is to the right center of Fig. 9, and only 180 deg of the scan is shown. This provides a blow-up of the target.

The near-vertical white line to the far left is the corner member. Note the clearly visible anodes on this member. The remaining vertical lines to the left of the corner member are the vertical risers.

In Fig. 10 the range was changed to 40 m, and the sector viewed in 180 deg. Thus it is 40 m across the screen. Note again the anodes on the corner member to the left center of Fig. 10.

In viewing the video tapes, the anodes are much clearer than in the photographs.

View 4

Fig. 11 shows another profile view of the platform structure with the sonar head moved closer in to the structure. The range setting is 20 m and the scan angle is 270 deg. The corner member appears as a vertical line near the lower center of Fig. 11. Again, what appears to be an anode is barely visible on the corner leg.

Fig. 12 shows a profile view of the same corner, with a range setting of 40 m. Fig. 4(c) shows the approximate location of the sonar head with respect to the corner of the platform.

View 5

In Fig. 13 a profile of a drill platform jack-up leg is shown. The sonar head was located off the corner, as in Fig. 4(a), position 3. The approximate distance of the sonar head from the jack-up leg is 10 m, and the range setting is 40 m. Very little detail is shown in the image of the jack-up leg, which is in the left center of Fig. 13. We note that the jack-up leg structure is quite complex.

CONCLUSIONS

As indicated from the photographs of the sonar images shown in the previous section, no exceptional images of the platform structure were obtained. These results were limited by the placement of the sonar head, the environmental conditions, and the equipment itself. A discussion of these factors and possible solutions follows.

In reference 1, some excellent images of an offshore platform are shown. These results were obtained by suspending the sonar head within the structure, or within a few meters of the structure from the outside. This method of deployment was not used in our tests because our intent was to simulate a stand-off inspection. Our results indicate that a stand-off inspection may not be possible without some equipment modifications.

Another degrading factor in our test results was acoustic noise due to continuous activity at the platform. For example, the platform was continuously discharging water, and a supply boat was operating at the platform during the test period. These operations caused air bubbles and turbulence in the path of the sonar beam. This was the source of much of the noise evident in the results. This type of noise in the images could probably be reduced by averaging several images.

Let us consider the inherent limitations in the equipment tested. The horizontal beam width of the AS 360 is the dominant factor in its potential resolution. A horizontal beam width of about one deg is required to resolve an object of 15 cm at a distance of 50 m. Another limitation is the 27 deg vertical beam width, which probably contributes to undesired returns in the images. Ideally, a pencil beam system would be desirable. However, this type of scanning beam would require rotation about both the horizontal and vertical axes (mechanically or electrically). Another improvement would be to increase the pixel dynamic range from 3 bits to some higher-value, 6 or 8 bits.

RECOMMENDATIONS

A stand-off inspection of an offshore platform from 50 m is not feasible with current commercial scanning beam sonar equipment. In an informal technical discussion with NRL, UDI, and SUB MAR representatives, the following possible equipment improvements were arrived at.

1. Image averaging - Some of the noise evident in the images appears to be random and uncorrelated. This type of noise can be reduced by averaging the image pixels over several scans. Because the images are digital and stored in a memory matrix, the averaging could be implemented by software and minimal hardware modifications.

2. Beam Width Reduction - Another suggested modification is to reduce both the transmit and receive horizontal beam widths by about a factor of two. This modification would require a reduction in the scan rates presently used.

3. Pencil Beam System - This is a complex modification which would require scanning about the vertical axis, in addition to the horizontal axis scan. The concept here is to build up an image of the area to be viewed in a line by line manner. With this concept, it would require up to 1 hour to scan and store an image (depending on the scan rates and angles selected).

4. Sensor Motion - Distortion caused by sensor motion (straight members appear curved) is evident in several photographs. An operational system using sonar scanning techniques would require that the sensor be rigidly anchored to eliminate ocean current-induced sensor motion.

5. Sensor Positioning - The scanning beam sensor head must be positioned at appropriate points around the platform. A bottom crawling system is probably not feasible because it would get tangled in debris around producing platforms.

6. Optimal Sensor Placement - Consider the following findings in the scanning beam sonar trials.

(i) The best images of the platform inspected were obtained when the scanning head was placed within 3 to 5 meters of the platform. Note that the desired viewing distance is 15 to 30 meters in an unannounced inspection.

(ii) The scanning sonar head was deployed from a jack-up barge with a heavy weight suspended under the sensor to reduce current-induced swing. Although the sea state was ideal, some distortion due to sensor swing was evident in several images.

Due to findings (i) and (ii), we conclude that an AS 360 type scanning beam sonar must be located on the ocean floor and close to the platform to be observed.

It is recommended by NRL that the Minerals Management Service consider funding additional testing on a scanning beam inspection system with the features described in modification 1 and 2 above.

REFERENCES:

1. Cattanach, D., and Cookson, E. W., "TV-Like Pictures at 100 Meters," Sea Technology, V. 24, No. 7, July 1983, pp. 41-45.

TABLE 1 - AS 360 SONAR HEAD DATA

Physical		
Height		= 35 cm
Diameter		= 21 cm
Weight		= 11 kg (in air)
		= 2 kg (in water)
Operational		
Transmission	Frequency	= 500 kHz
	Pulse Width	= 100 microseconds
	Beam Width	= 1.4 deg horizontal
		= 27 deg vertical
Receiver Beam Width		= 3.4 horizontal
		= 27 deg vertical
Angular Scan Rate @ Range		= 18 deg/sec @ 10m
		= 18 deg/sec @ 20 m
		= 12 deg/sec @ 40 m
		= 7.2 deg/sec @ 100 m
Depth Rating		= 750 m

TABLE 2 - AS 360 DISPLAY AND CONTROL UNIT

Physical	
Height	32 cm
Width	44 cm
Depth	41 cm
Weight	33 kg
Power	
110/240 Volts ± 10%, automatic selection	
150 VA	
CRT	
9 inch video monitor	
256 x 256 pixels with 8 grey levels	
Video Output (BNC)	
Display Mode	
PPI with 10/20/40/100 meter range	
Scan Mode - Forward/Reverse/Autoscan	
15/30/60/90/180/270 deg scan angle	
Variable Scan Position	
Automatic/Manual Gain	

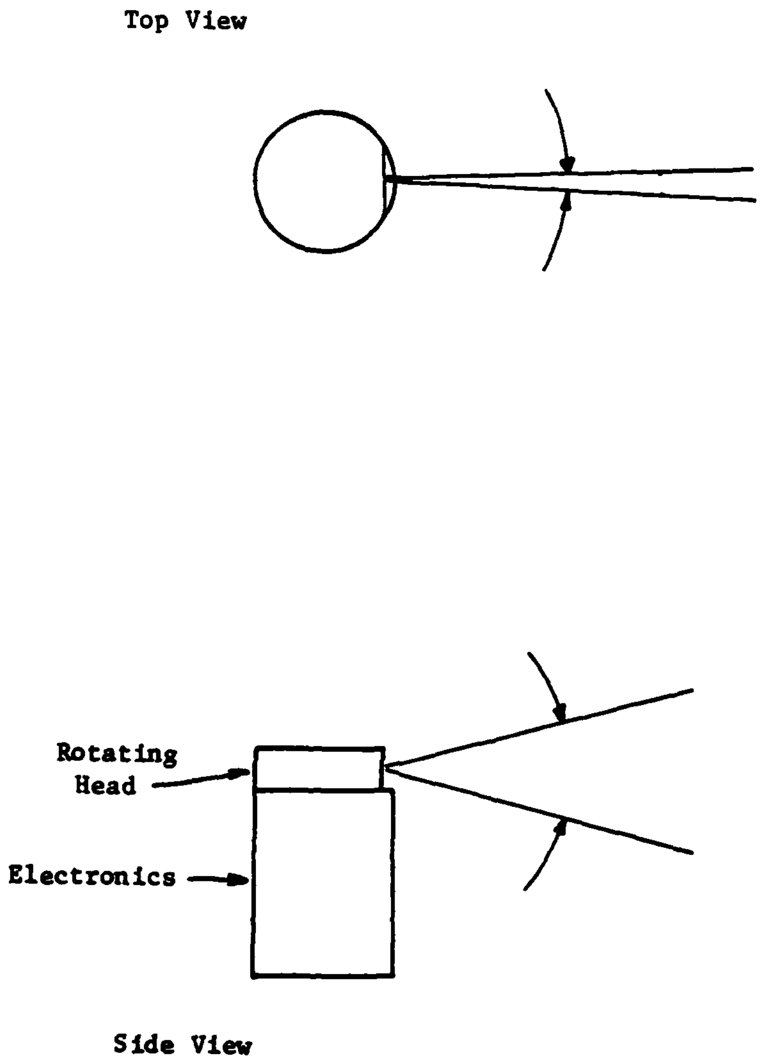


Fig. 1 — Scanning beam sonar

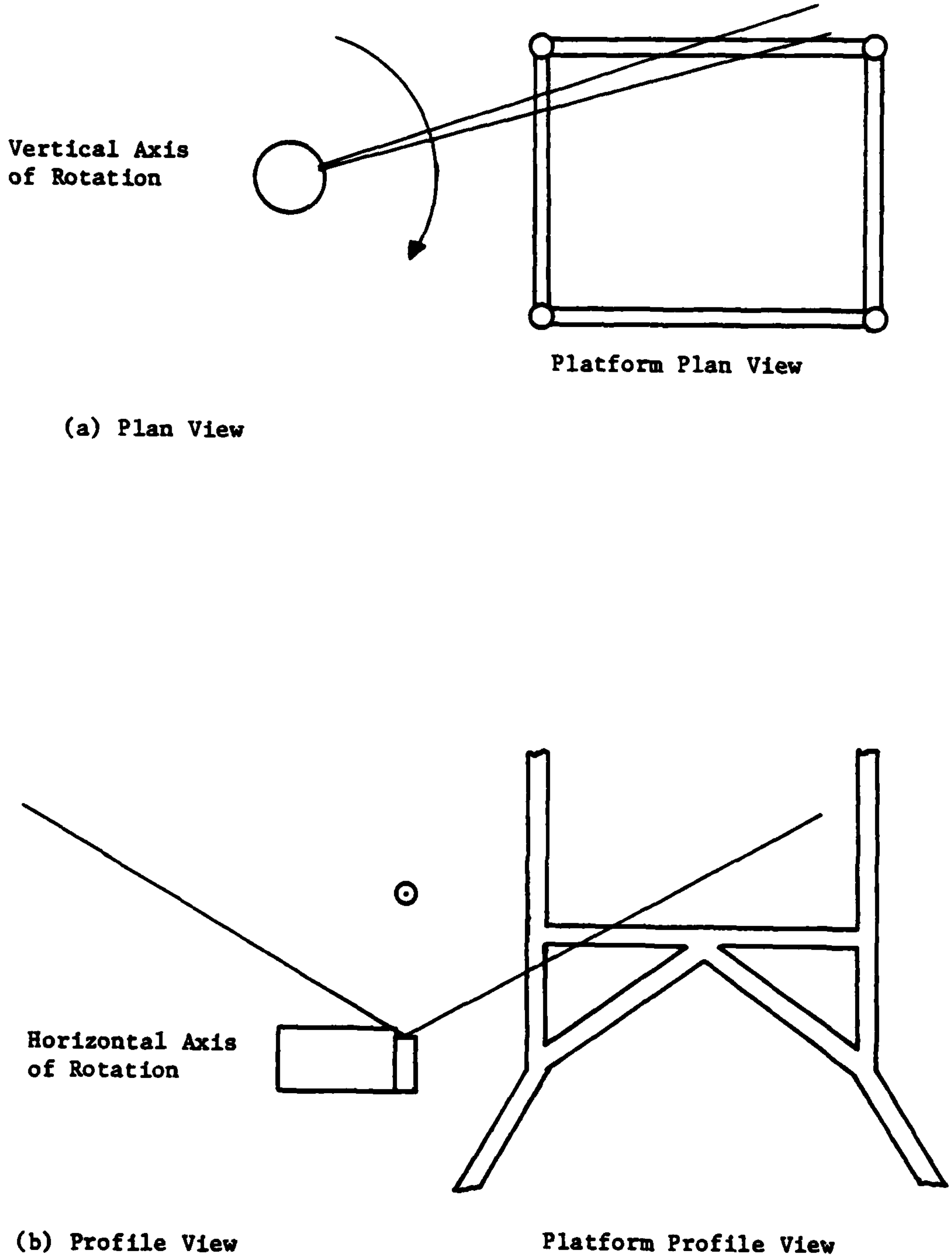
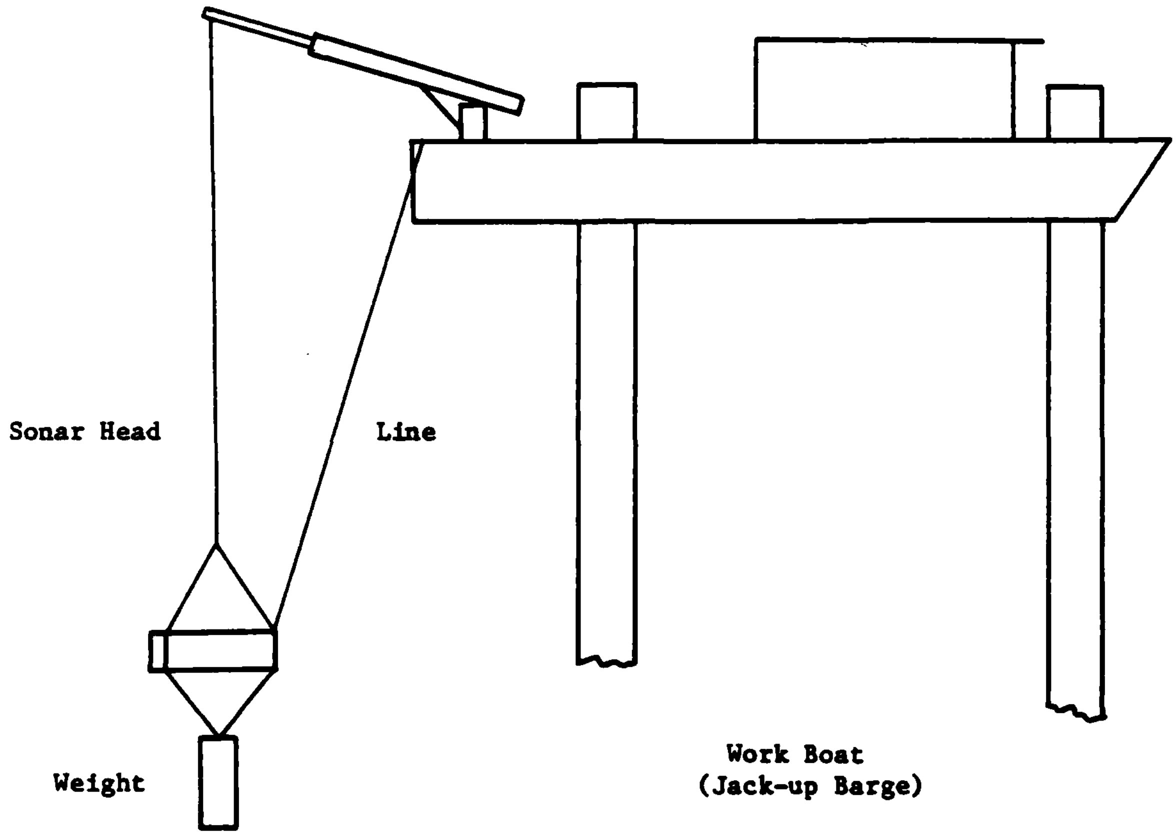


Fig. 2 — Plan and profile view modes



Fi~ 3 — AS 360 deployment

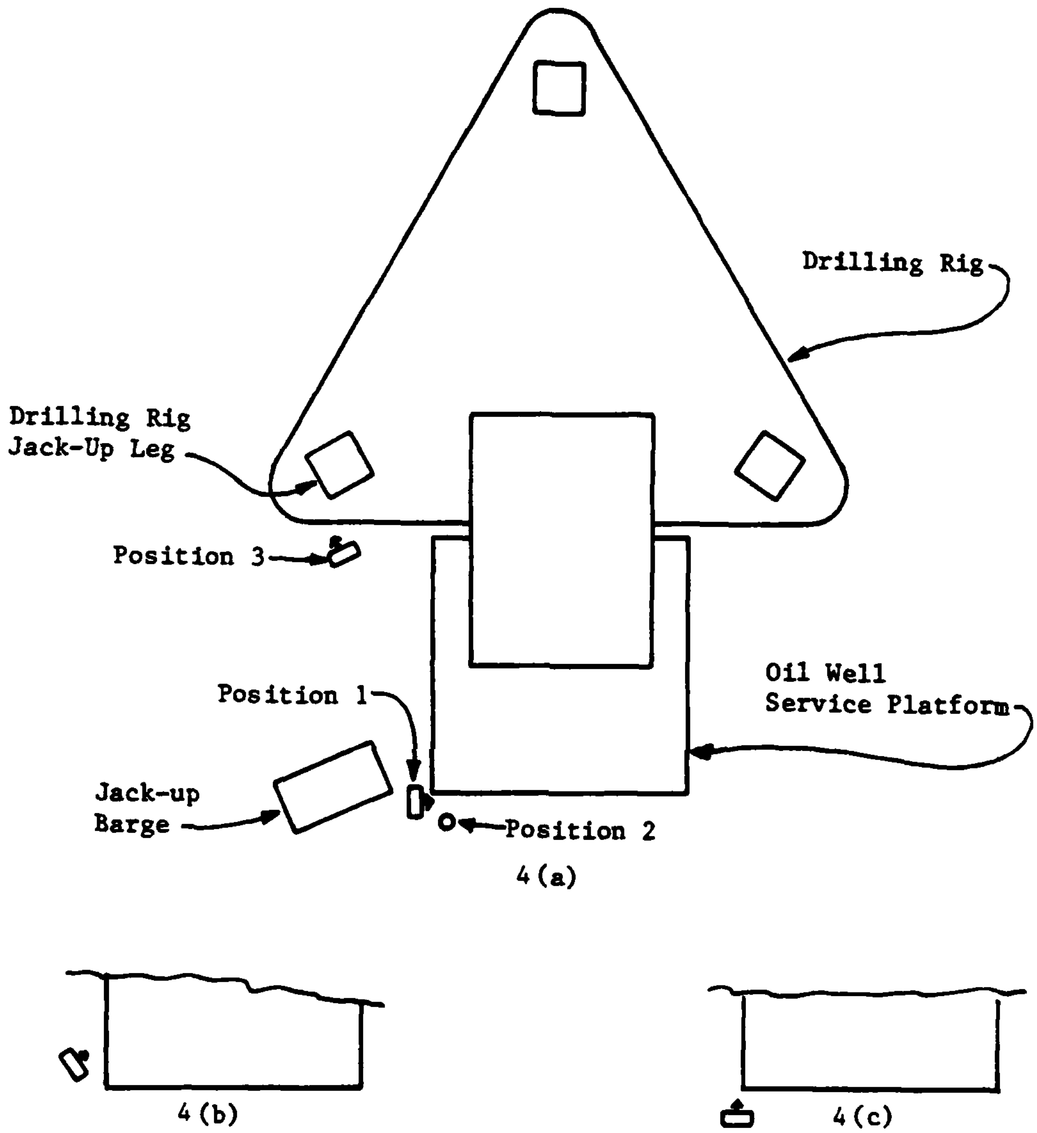


Fig. 4 — General layout and data points

Fig. 5 — Profile view of production platform

Fig. 6 — Plan view of production platform

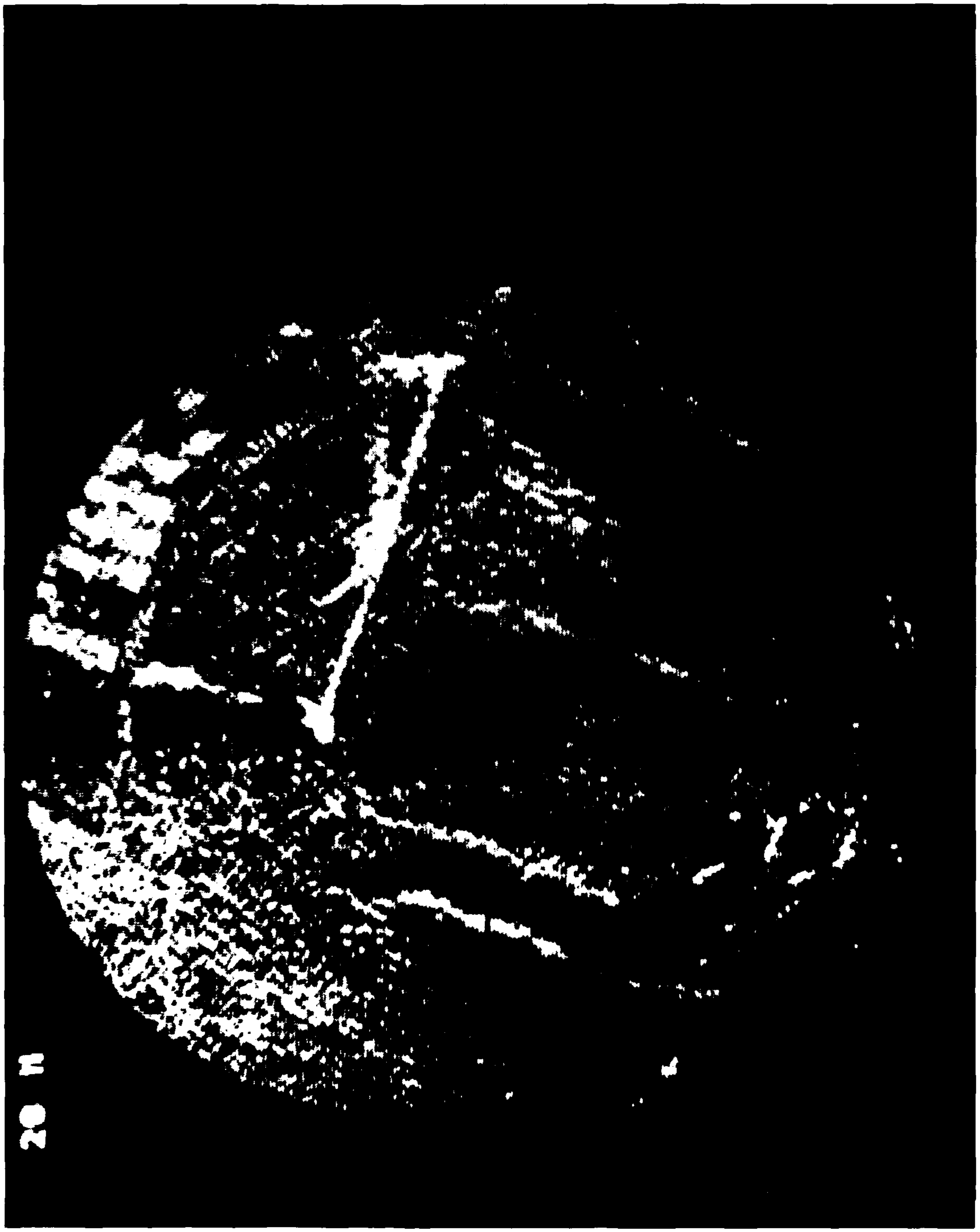


Fig. 7 — Plan view of production platform

Fig. 8 — Profile view of production platform

Fig. 9 — Profile view of production platform

Fig. 10 — Profile view of production platform

Fig. 11 — Profile view of platform structure

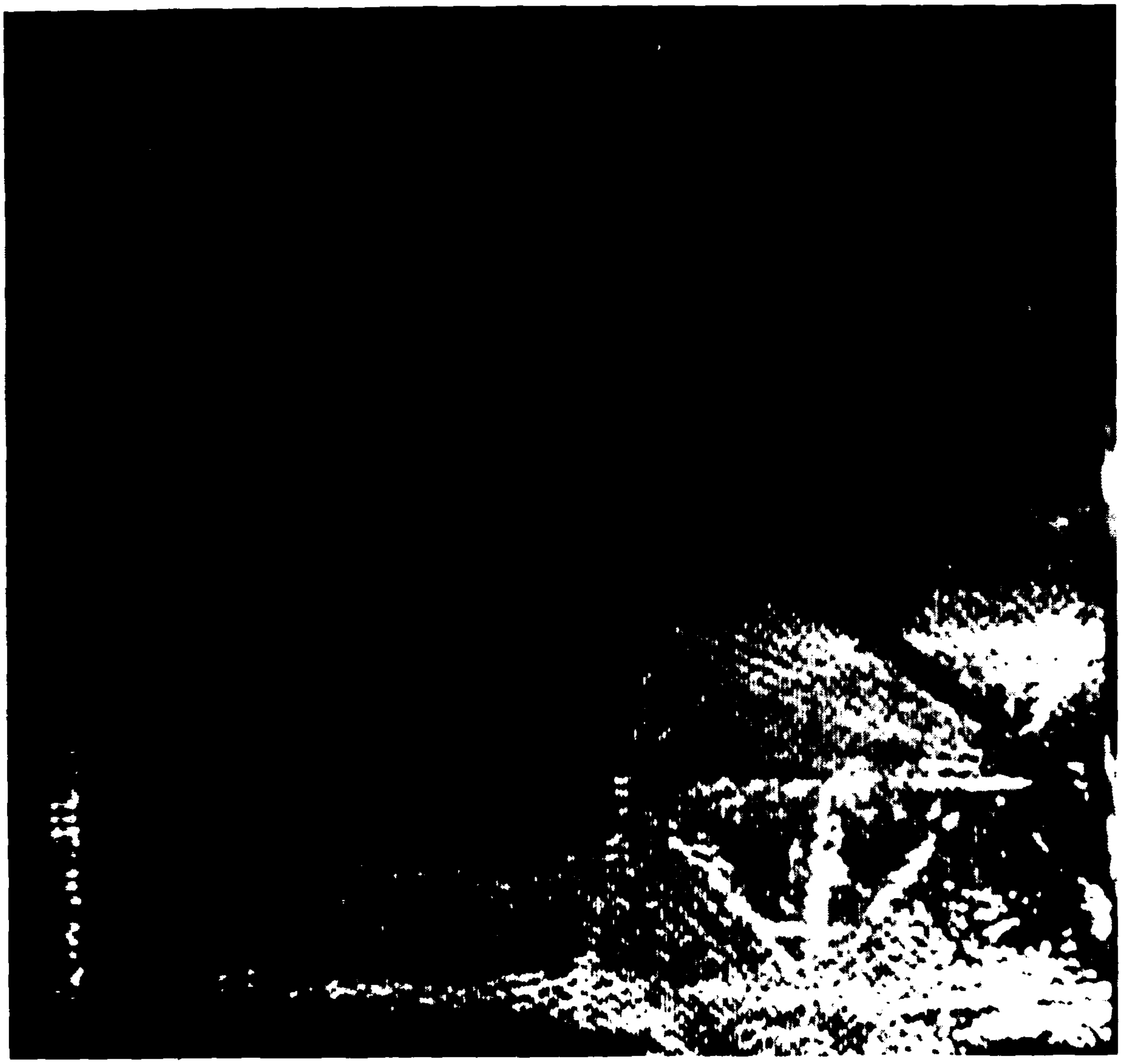


Fig. 12 — Profile view of platform structure

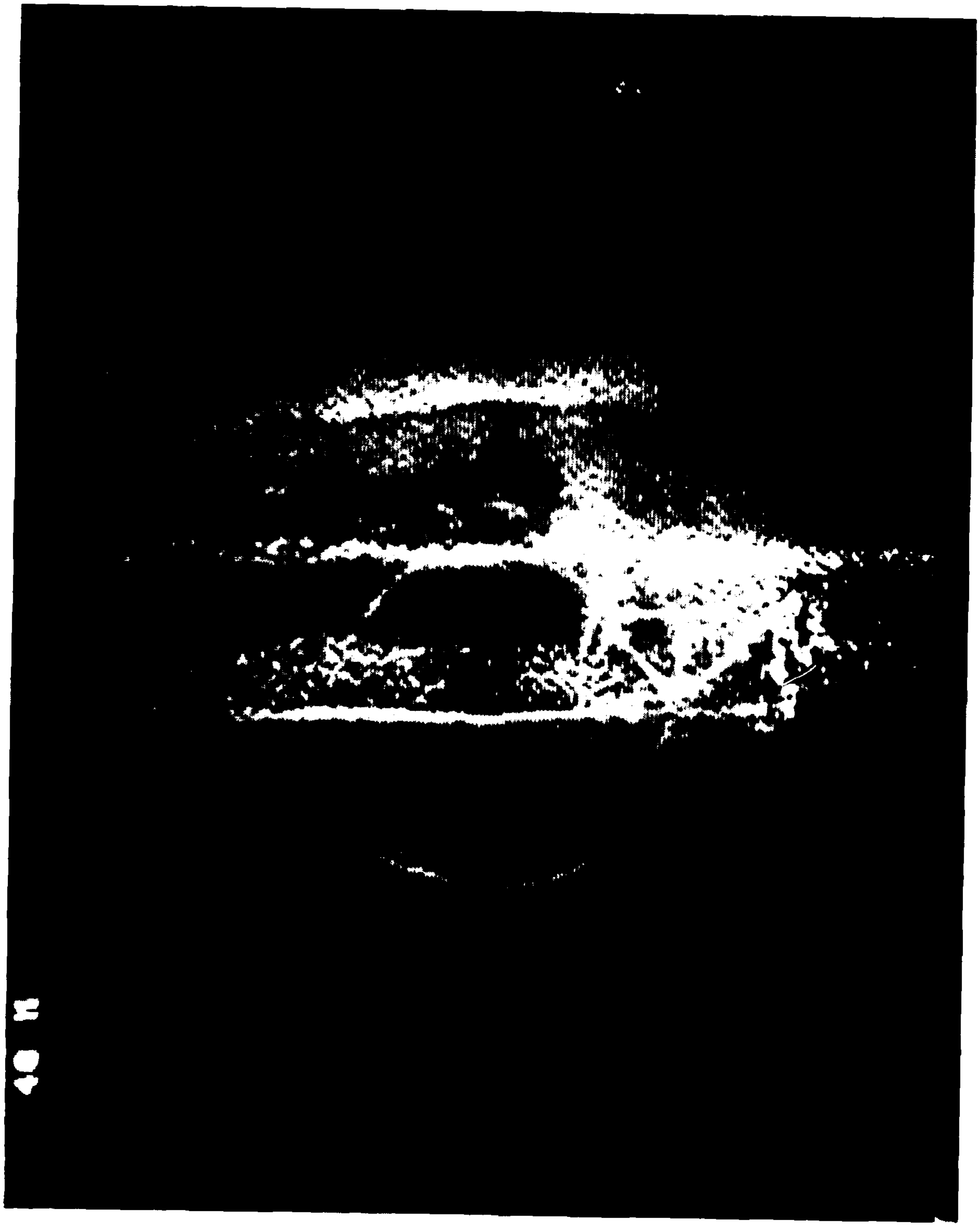


Fig. 13 — Profile view of jack-up leg

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